A FAST INTRA-PREDICTION DECISION ALGORITHM IN INTER-FRAME BASED ON A NOVEL FEATURE OF HEVC

*Tingting Wang, Yangyang Men, Yihao Zhang, Hongyang Chao**

Sun Yat-sen University, Guangzhou, China

ABSTRACT

With the quad-tree based coding structure and more flexible intra-modes, the coding efficiency provided by intra-technique in inter-frames of HEVC is much higher than the preceding standard H.264/AVC. However, the computing complexity is also significantly increased. Although only a few CUs are encoded as intra-mode in inter-frames finally, almost all CUs need to be checked all the intra-options to obtain the optimal mode, which may be in fact unnecessary. Unlike most existing fast algorithms, which focus on accelerating intra-prediction itself, we propose a novel feature to quantitatively estimate the possibilities of doing intra-prediction for CUs. Based on this feature, we further design a fast intra-prediction decision algorithm to determine whether a CU needs to be checked the intra-prediction. The experimental results show that our algorithm can reduce more than 60% computing resources with a negligible loss in rate-distortion performance for intra-module in all inter-frames. Besides, our method can be compatible with all other existing fast algorithms.

***Index Terms*—** HEVC, Inter-frame, Intra-prediction, Motion Strength Count

1. INTRODUCTION

Compared with H.264/AVC[1], intra-coding technology in HEVC[2] achieves 22%[3] bitrate reduction with equal subjective quality. However, the cost of this improvement is relatively high because of traversing the quad-tree with 35 intra-modes exhaustively.

To analyze the impact of intra-module for inter-frames in HEVC, we have done some experiments shown in Table 1. The test sequences are selected from class A-E defined in [4]. The results in the second column indicate that intra-prediction makes a significant contribution to the overall coding efficiency, 5.29% coding efficiency improvement on average and up to 10%, which cannot be ignored. On the other hand, intra-prediction costs as much as 21.49% resources (third column) even if the early skip mode[5] and rough mode decision (RMD)[6] have been used, which is a considerable percentage of the total computations of inter-frame coding. Therefore, the optimization of intra-technology in inter-frames is definitely necessary, which is also our focus.

Table 1. The impact of intra-prediction for inter-frames in HEVC.

Class	BD-rate	Time cost	Intra-block percentage
A	-5.93%	23.76%	7.03%
B	-10.26%	22.19%	6.65%
C	-5.59%	25.79%	10.27%
D	-3.99%	21.93%	4.84%
E	-0.70%	13.78%	0.39%
Ave.	**-5.29%**	**21.49%**	**5.84%**

This work is partially supported by NSF of China under Grant 61672548, U1611461, 61173081, and the Guangzhou Science and Technology Program, China, under Grant 201510010165.

*Corresponding author: Hongyang Chao.

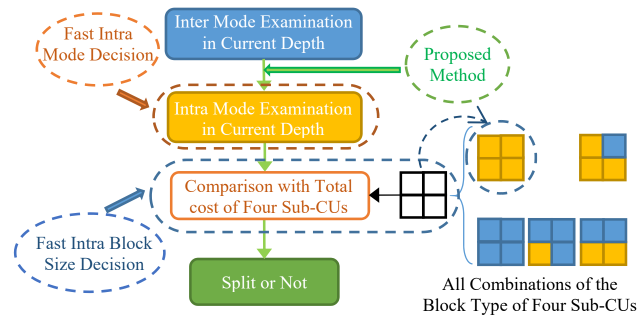


Fig. 1. Mode decision process in inter frame.

From the last column in Table 1, we can further observe that the ratio of intra-blocks is only 5.84% averagely, which is much lower than that of inter-blocks. However, to find this very few part, we need to traverse all the 35 intra-modes in each size of coding unit (CU) on the entire frame, which is apparently a computing waste. In opposite, it is also a direction of optimization to avoid the above waste. This paper aims at solving this problem.

A number of efforts have been already made to reduce the complexity of intra-prediction in HEVC. Some of them focused on fast finding the right selection from all 35 modes. Others aimed at the fast intra-block size decision, which tried to early terminate the further splitting of an intra-block. Nonetheless, as shown in Fig. 1, these works only decrease the complexity of the intra-prediction examination itself, and the problem mentioned above is not well taken into account; that is, how to avoid the unnecessary intra-prediction in inter-frames is not completely solved. Details will be discussed in Section 2.

The straightforward solution to this issue is to obtain the information of each CU's optimal mode, intra/inter type, in the topmost stage to omit all the following time-consuming checks of full intra-mode candidates. However, it is impossible to be achieved before the decision procedure is done. In addition, because of the diversity and the complexity of video contents, it is difficult to establish a mathematical model that can precisely predict the specified mode for each CU with little or no computational overhead. So, solving this problem is hard.

In order to overcome the aforementioned difficulties, we are going, in this paper, to estimate the possibilities of adopting the intra-prediction for all blocks, and examine intra-prediction in CUs with higher possibilities and skip those with lower chances.

There are mainly two contributions in this work. First, we propose a novel feature – Motion Strength Count (MSC), for quantitatively describing the possibility of adopting intra-prediction for CUs in inter-frames. Second, by utilizing MSC, we further design a fast algorithm for intra-prediction decision in inter-frames. Experimental results confirm that the proposed algorithm achieves more than 60% time reductions for intra-module with negligible rate-distortion performance loss. Besides, the proposed method can be compatible with all other existing fast algorithms as shown in Fig. 1. It determines whether current CU needs to be checked intra-coding before the real intra Rate-Distortion Optimization (RDO). Once the intra-prediction examination in current depth starts, other fast algorithms can be applied.

The rest of this paper is organized as follows. In Section 2, some related works will be introduced. Section 3 describes the motivation and the proposed novel feature. Then a fast intra-prediction decision algorithm by using this feature will be shown in Section 4. We list the experimental results in Section 5 to evaluate the accuracy of the proposed method. Finally, we give the conclusions and forecast the future works in Section 6.

2. RELATED WORKS

Recently, there are extensive works on reducing the complexity of intra-prediction, similar with the fast search technique in inter motion estimation. They are mainly classified into two categories: fast block size decision for intra-coding and fast intra-prediction mode decision, which are summarized as follows.

Owing to many different CU sizes, from 8x8 to 64x64, which will cost a lot of time in intra-coding technology, the first kind of methods were proposed to study how to avoid the unnecessary further splitting of intra-blocks. In [7]–[9], they utilized the texture information to determine whether current intra-coded CU needs to be further split. [10] proposed a fast CU size decision algorithm similarly. It designed four-direction edge complexities to decide the CU size for intra-prediction, which achieved about 50% acceleration for intra-module with 0.8% BD-rate increments.

Besides, accounting for the other time expensive part, where each prediction unit (PU) in every CU examines 35 intra-prediction modes, the second type of fast algorithms works in the rough mode decision (RMD) fashion to filter the fewer intra-mode candidates in the full RDO with a low-complexity cost ranking rather than a brute-force manner. [6][11][12] aimed at quickly determining the most effective intra-prediction candidates instead of searching all modes in an exhaustive way. Piao et al.[6] posed the RMD algorithm which roughly compared all modes by the absolute sum of Hadamard Transformed coefficients of residual signal (HSAD) before the full RDO procedure. Only N best candidate modes will do the full RD search. Zhao et al. [11][12] tried to further simplify the intra-coding complexity of encoder by reducing the number of mode candidates based on RMD.

The studies provided by [13] and [14] considered about these two problems together. The methods discussed in [14] explored the correlations between the current CU and the parents or spatially nearby CUs to skip some rarely used depth and intra-mode candidates. [13] further exploited the information of neighbored CUs correlated with current one to early terminate and selectively check the potential intra-modes progressively. 2.5 times speedup with 1.0% BD-rate loss can be achieved in this method.

Despite the fast algorithms of intra-coding have already accelerated a lot, the intra-mode checking in every CU is still needed, even if that block is finally inter-coded. These unnecessary checks waste a lot of time and computing resources. Therefore, if the possibility of employing intra-prediction for each CU can be estimated beforehand, the load of the intra/inter mode decision can be reduced dramatically. Yet to our best knowledge, the solution to the above problem in HEVC has not been well studied.

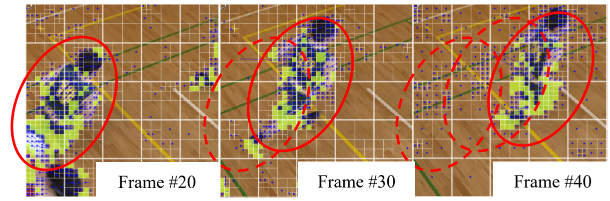


Fig. 2. An example of the distributions about intra-coded blocks and motion vectors in BasketballDrill frame #20, #30 and #40 with the optimal CU partitions. The intra-blocks and MVs are marked with yellow and blue respectively. The trajectory of the moving player in three continuous frames is marked by red circle.

3. PROPOSED FEATURE: MOTION STRENGTH COUNT (MSC)

In this section, a novel feature for estimating the possibility of applying intra-prediction of a CU will be described. We will start with the motivating observations, which can help model the correlations between the intra-prediction and the motion of an object in continuous frames. The formulation of MSC will be discussed in the second subsection.

3.1. Observations

Fig. 2 gives an example to show our motivating observations with the help of HEVC Analyzer[15]. It is easy to see that, in these three frames, the intra-blocks incline to cluster on the moving objects (players) rather than the static background, and moreover, the intra-blocks always move along with these moving objects. The essence of those phenomena is, in the areas near the moving objects, the non-rigid deformations and new contents occur continuously, which the inter-prediction cannot handle well. As briefed in Section 1, directly determining whether a block should be employed intra-prediction before full RDO is difficult, but if the intra-blocks' positions in the frames to be coded can be predicted, we can just employ intra-prediction in the areas with higher possibilities. Consider about the above observations, solving the problem of predicting intra-blocks' locations turns to how to determine the intensity of object's motion and where the objects will move to in current frame. To solve these two issues, a novel feature, MSC, has been designed, which will be introduced next.

3.2. A novel feature: Motion Strength Count (MSC)

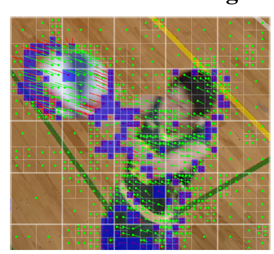


Fig. 3. MVs of inter and intra-blocks. The green lines are inter-MVs and the red ones are intra-MVs compensated as defined in [16]. Intra-blocks are marked with blue.

In this subsection, the new feature Motion Strength Count (MSC) will be described detailedly.

As mentioned before, to predict the possible region of intra-blocks, we need to find a way to evaluate the intensity of the motion of objects and predict the position of the moving object in every frame. As the movement of an object is continuous, the motion information of current frame can be predicted by the adjacent frames. If the CUs on the moving object are inter-coded, the motion intensities and positions of those CUs in the next frame are easy to be obtained by the lengths of their MVs and MVs' opposite directions. However, for the intra-CUs, it is difficult to apply the same process, since we cannot derive the intra-MVs straightly. With the help of the method demonstrated in [16], we compensate the MVs of intra-blocks from the four neighbored inter-coded CUs in the directions of top, bellow, left and right respectively. Fig. 3 shows the compensated intra-MVs.

The motion strength of objects can be estimated by the MVs' magnitudes. Accumulating all the weighted magnitudes of the intra/inter MVs in a certain CU, we get the corresponding MSC, which is defined as follows:

$$\mathrm{MSC} = \sum_{i\in\beta}(d_i * \|MV_i^{n-1}\|) + \omega * \sum_{j\in\alpha}(d_j * \|MV_j^{n-1}\|) \quad (1)$$

where $\{MV_i^{n-1} | i \in \alpha\}$ and $\{MV_j^{n-1} | j \in \beta\}$ are the sets of all the inter-MVs and intra-MVs respectively, coming from frame #n-1 and located in the same CU in frame #n; considering the intra-coded blocks around moving object is continuous, intra-blocks in previous frames should contribute more to the next frame's intra-location, the ω is the weights of intra-MVs which is set to 5 empirically, d_i is the depth of the CU_i^{n-1} containing MV_i^{n-1}, which ranges from 1 to 4 following the CU size from 64x64 down to 8x8, because the larger deformation areas are more likely coded with smaller blocks[17]. An example of MSC calculation for a largest CU (LCU) in a frame is shown in Fig. 4.

Fig. 5 depicts a real-world example to verify the effectiveness of MSC. It shows the correlation between the value of MSC in each LCU and the distributions of intra-coded blocks and MVs. From the highlighted regions we can observe that intra-blocks incline to emerge in the LCUs with high MSC values.

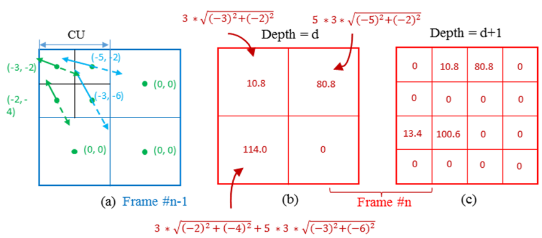


Fig. 4. An example of MSC calculation for frame #n. (a) Coding information of frame #n -1. Green arrows depict the inter-MVs and the blue ones are intra-MVs. The numbers shows the values of x and y components of MVs. (b) MSC map for depth 2 of frame #n. (c) MSC map for depth d+1 of frame #n.

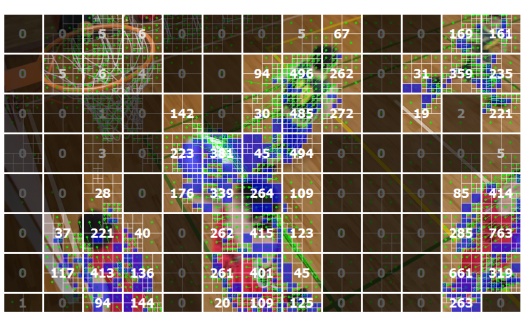


Fig. 5. An example of the relationship between MSC and Intra-Mode of BasketballDrill frame #24. Intra-blocks are in blue. The MVs are depicted by green lines.

4. DECISION ALGORITHM

Based on the proposed feature in Section 3.2, we will describe our fast intra-prediction decision algorithm and discuss the way of the thresholds selection.

4.1. Overall algorithm

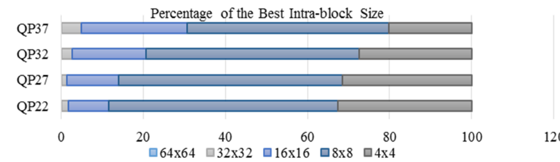


Fig. 6. Percentage of the best intra-block size in inter-frames.

Once the previous frame is coded, the current frame's MSC map for each CU depth can be obtained by simple computations. According to the percentage of the best intra-block size in inter-frames depicted in Fig. 6, obtained by some test sequences, we can observe that the size 8x8, 4x4, and 16x16 are the major intra-block sizes in inter-frames. Considering this fact with the MSC feature, we utilize the MSC in depth 1 and 2 to filter the areas which are most likely to be coded as intra, and only examine the intra-prediction of small blocks (16x16 ~ 4x4) in these areas, which can significantly avoid the unnecessary intra-mode checks. The steps of algorithm in each LCU are described as follows:

1) In depth 1, if the MSC value of current depth, MSC_i^d, exceeds *TA* , this CU has more possibility to be coded as intra-mode in the further depth. Set the flag *further_splitting* to be true, go to step (2); else skip the intra-modes check in current depth and set the flag *further_splitting* to be false, go to step (4).

2) In depth 2, if the MSC_i^d is larger than *TA* or the mean value of the 8-neighbors' MSCs is larger than *TB*, this CU has more possibility to be coded as intra-modes in current depth and further depths. Check intra-mode in current depth and set the flag *further_splitting* to be true, go to step (3); else skip intra-mode check in current depth and set the flag *further_splitting* to false, go to step (4).

3) In depth 3-4, always check intra-mode.

4) Skip the intra-mode checks in further depths.

Because that the first two depths remove the unnecessary intra-mode checks precisely, the computing burden can be reduced dramatically.

4.2. Thresholds Selection

Table 2. Relationship between *TA, TB* and coding performance.

TA	BD-rate	Intra-Time Saving	TB	BD-rate	Intra-Time Saving
17	0.129%	51.9%	40	0.196%	62.0%
23	0.136%	56.6%	50	0.218%	64.3%
27	0.160%	58.8%	65	0.276%	65.4%
33	0.178%	61.1%	99	0.295%	66.3%

Thresholds *TA* and *TB* are applied to filter the unnecessary intra-mode examinations in the first two depths progressively. If they are too small, more small blocks will be checked the intra-prediction that leads to a better coding efficiency but less time reduction. Table 2 depicts the relationships between the thresholds and coding performance tested on all the sequences from class A-E with 50 frames. For a trade-off between the coding efficiency and the time reduction, we set TA = 33 and TB = 43 in this paper.

5. EXPERIMENTAL RESULTS

In this part, three experiments have been done to evaluate the performance of our algorithm. Our experiments are performed on the reference software HM15.0[18], which is also the anchor. Test sequences come from all classes in [4] except class F, because it contains the screen contents of which the motions sometimes are not continuous. Test sequences are compressed with Lowdelay-P configuration. QPs are 22, 27, 32 and 37.

Firstly, Table 3 indicates the overall performance comparison between the proposed method and the anchor. A positive value of BD-rate means the coding performance loss compared with baseline. ΔITS and ΔTTS indicate the intra-prediction time saving and the total time saving respectively.

Table 3. Performance for proposed fast algorithm on HM15.0.

Class	Sequences	BD-rate	ΔITS	ΔTTS
A	Traffic	0.066%	69.1%	13.6%
	PeopleOnStreet	0.091%	32.9%	11.9%
B	Kimono	0.456%	53.4%	15.0%
	ParkScene	0.290%	57.0%	15.0%
	Catus	0.576%	54.0%	14.1%
	BasketballDrive	0.375%	31.0%	4.2%
	BQTerrace	0.296%	67.0%	12.1%
C	BasketballDrill	0.386%	45.3%	8.0%
	BQMall	0.236%	44.5%	7.9%
	PartyScene	0.052%	47.2%	10.8%
	RaceHorses	0.013%	20.2%	3.7%
D	BasketballPass	-0.201%	54.3%	7.6%
	BQSquare	-0.244%	61.3%	12.0%
	BlowingBubbles	0.432%	44.9%	7.7%
	RaceHorses	-0.124%	15.6%	2.5%
E	FourPeople	0.433%	86.3%	8.3%
	Johnny	0.237%	96.1%	8.6%
	KristenAndSara	0.192%	92.8%	8.3%
Ave.		**0.198%**	**62.9%**	**9.6%**

As can be observed from Table 3, our proposed method can averagely save more than 60% intra-coding time with less than 0.2% BD-rate increment. The time reductions in different test sequences change in large ranges, e.g., the time of intra-coding can be saved significantly in the sequences of class E whereas only around 20% time reduction in two Racehorses sequences. The main reason is the time saving mainly depends on how many motionless areas can be omitted in inter-frames. If the sequences contain lots of static backgrounds such as those in class E, the MSC of these regions must be low, intra-prediction might not be the best mode for those areas. Thus, time of intra-prediction can be reduced efficiently. But for the sequences with many moving objects like Racehorses, most blocks will be encoded as intra, and intra-mode checks on them are necessary. So the intra-time reduction is relatively low. Despite this, the proposed approach can still reduce a considerable account of computation load with little coding efficiency loss on average.

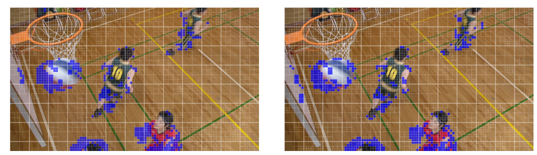
Secondly, comparisons with [10] and [13] are provided in Table 4, since both of them are the state-of-the-art fast algorithms. [10] focuses on the fast intra-block size decision, and [13] is a combination of the intra-mode decision and intra-block size decision. BD-rate and the time reduction of intra-prediction with Lowdelay-P configuration for class B-E are presented. It shows that the coding efficiency of the proposed method is much better than the state-of-the-arts and the time reduction is competitive as well. In addition, all the existing fast algorithms are compatible with ours to achieve more speedup, because all the fast algorithms can be applied to the necessary intra-block examinations which are determined by the proposed method.

Table 4. Comparisons with [10] and [13] in class B-E.

Class	Proposed		[10]		[13]	
	BD-rate	**ΔITS**	**BD-rate**	**ΔITS**	**BD-rate**	**ΔITS**
B	0.4%	53%	0.5%	50%	0.7%	61%
C	0.2%	39%	0.4%	48%	1.0%	57%
D	0.0%	44%	0.3%	44%	0.8%	54%
E	0.3%	92%	0.8%	63%	1.1%	65%
Ave.	**0.2%**	**57%**	0.5%	51%	0.9%	59%

Table 5. Hit rate of prediction type of our method in QP 22-37.

QP / Class	22	27	32	37
A	92.7%	95.7%	96.9%	97.5%
B	88.6%	96.1%	97.0%	97.1%
C	94.5%	95.8%	95.9%	95.9%
D	99.1%	98.7%	98.1%	97.7%
E	98.6%	99.7%	99.8%	99.9%
Ave.	**94.7%**	**97.2%**	**97.5%**	**97.6%**



(a) (b)

Fig. 7. The distributions of prediction mode of anchor and our proposed algorithm. (a). The baseline result of frame #6 in BasketballDrill. (b). Result of our proposal. Blue blocks indicates the intra-coded CUs.

Lastly, to illustrate the accuracy of the decision algorithm based on MSC, we also list the hit rate of prediction type in four QPs in Table 5. The hit rate is the percentage of the matching prediction mode between baseline and our proposed method. Moreover, an example of visualized prediction mode of each CU in baseline and our method is shown in Fig. 7. All the results justify our method can accurately remove the unnecessary intra-prediction.

In summary, all the experimental results aforementioned indicate the proposed feature MSC and the fast intra-prediction decision algorithm are effective and accurate indeed. It can achieve desirable compression efficiency and save considerable coding time.

6. CONCLUSIONS

Different from most existing fast algorithms, in this paper, a novel feature MSC is proposed to quantitatively predict the possibilities of checking intra-prediction for CUs. Furthermore, a fast intra-prediction decision algorithm is designed based on MSC to determine whether a CU needs to be examined intra-prediction in inter-frames. The experimental results confirm that our algorithm can reduce over 60% computing time with less than 0.2% increment in BD-rate for intra-prediction procedure in all inter-frames. As a preliminary result, we show the speedup gain by exploiting the proposed algorithm. Besides, the proposed fast algorithm can be compatible with most existing fast algorithms which can further speed up the intra-prediction time in inter-frames. Nevertheless, there are still some rooms to improve. Extending the calculation of MSC from P frames to B frames and selecting the two thresholds adaptively according to the video's content are our future works.

7. REFERENCES

[1] T. Wiegand, "Overview of the H.264/AVC video coding standard," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 13, no. 7, pp. 560 –576, 2003.

[2] G. J. Sullivan, J. R. Ohm, W. J. Han, and T. Wiegand, "Overview of the high efficiency video coding (HEVC) standard*," IEEE Trans. Circuits Syst. Video Technol.*, vol. 22, no. 12, pp. 1649–1668, 2012.

[3] J. Lainema, F. Bossen, W. J. Han, J. Min, and K. Ugur, "Intra coding of the HEVC standard," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 22, no. 12, pp. 1792–1801, 2012.

[4] F. Bossen, "Common test conditions and software reference configurations," *Jt. Collab. Team Video Coding (JCT-VC)*, JCTVC-F900, 2011.

[5] J. Kim, J. Yang, K. Won, and B. Jeon, "Early determination of mode decision for HEVC," *Pict. Coding Symp. PCS 2012, Proc.*, pp. 449–452, 2012.

[6] Y. Piao, J. Min, and J. Chen, "Encoder improvement of unified intra prediction," *JCTVC-C207*, 2010.

[7] G. Tian and S. Goto, "Content adaptive prediction unit size decision algorithm for HEVC intra coding," *2012 Pict. Coding Symp. PCS 2012, Proc.*, pp. 405–408, 2012.

[8] H. S. Lee, K. Y. Kim, T. R. Kim, and G. H. Park, "Fast encoding algorithm based on depth of coding-unit for high efficiency video coding," *Opt. Eng.*, vol. 51, no. 6, pp. 67401–67402, 2012.

[9] C. Zhou, F. Zhou, and Y. Chen, "Spatio-temporal correlation-based fast coding unit depth decision for high efficiency video coding," *J. Electron. Imaging*, vol. 22, no. 4, p. 43001, 2013.

[10] Biao Min and R. C. C. Cheung, "A Fast CU Size Decision Algorithm for the HEVC Intra Encoder," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 25, no. 5, pp. 892–896, May 2015.

[11] L. Zhao, L. Zhang, S. Ma, and D. Zhao, "Fast mode decision algorithm for intra prediction in HEVC," in *2011 Visual Communications and Image Processing (VCIP)*, 2011, pp. 1–4.

[12] L. Zhao, L. Zhang, X. Zhao, S. Ma, D. Zhao, and W. Gao, "Further Encoder Improvement of Intra Mode Decision," *JCTVC-B283*, pp. 1–8, 2011.

[13] H. Zhang and Z. Ma, "Fast Intra Mode Decision for High Efficiency Video Coding (HEVC)," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 24, no. 4, pp. 660–668, 2014.

[14] L. Shen, Z. Zhang, and P. An, "Fast CU size decision and mode decision algorithm for HEVC intra coding," *IEEE Trans. Consum. Electron.*, vol. 59, no. 1, pp. 207–213, 2013.

[15] H. Li, "Gitl HEVC Analyzer." .

[16] S. H. Khatoonabadi and I. V Bajić, "Video object tracking in the compressed domain using spatio-temporal Markov random fields.," *IEEE Trans. Image Process.*, vol. 22, no. 1, pp. 300–13, 2013.

[17] Y. Zhang, S. Huang, H. Li, and H. Chao, "An optimally complexity scalable multi-mode decision algorithm for HEVC," in *2013 IEEE International Conference on Image Processing*, 2013, pp. 2000–2004.

[18] I.-K. Kim, K. McCann, K. Sugimoto, B. Bross, W.-J. Han, and G. J. Sullivan, "High efficiency video coding test model 15 (HM 15) reference software," *Doc. JCTVC-Q1002*, 2014.